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Manual Control Aspects of Orbital Flight

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held at Ames Research Center,
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February 22, 1990

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Manual Control Aspects of Orbital Flight

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National Aeronautics and
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PREFACE

On February 22, 1990, several scientists and engineers from NASA and industry assembled at NASA Ames Research Center (ARC) to participate in the first workshop concerning manual control aspects of orbital flight. The goals of the workshop were to:

1. Exchange ideas among interested parties

2. Identify current and future research needs

3. Pave the way for future communication and collaboration, especially between ARC and Johnson Space Center

Workshop participants presented papers describing their research and/or their association's positions on various issues. Topics ranged from orbital trajectory displays to real-time simulation with timelines ranging from immediate to 10–20 years into the future. This document is a summary of that workshop. We wish to thank all of the attendees and offer the hope that readers will benefit from this summary.

Adam R. Brody, Sterling Software

Stephen R. Ellis, NASA Ames Research Center

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AGENDA

Stephen R. Ellis, ARC	Opening Remarks
Adam R. Brody, Sterling Software; ARC	Manual Control Aspects of Orbital Flight
Michael L. Veres, JSC	Orbital Maneuvering Vehicle Remote Piloting Operations
Craig S. Hartley, Martin Marietta	Results from Teleoperated Free-Flying Spacecraft Simulations in the Martin Marietta Space Operations Simulator Lab
Gary Gershzohn, MDAC	A Manned Maneuvering Unit Proximity Operations Planning and Flight Guidance Display and Control System
Arthur J. Grunwald, Technion Stephen R. Ellis, ARC	Interactive Orbital Proximity Operations Planning System
Jeff Soller, UC-Berkeley	Simulated Annealing in Orbital Flight Planning

SUMMARY

This publication provides a brief description of several laboratories' current research in the general area of manual control of orbital flight. This research began in the 1960's in preparation for the Gemini and Apollo programs, but documentation for any work performed over the last twenty years is virtually nonexistent. With an operational-space-station era (and its accompanying increased traffic levels) approaching, now is an opportune time to investigate issues such as docking and rendezvous profiles and course-planning aids. The tremendous increase in the capabilities of computers and computer graphics has made extensive study possible and economical. It is time to study these areas, from a human factors and manual control perspective, in order to preclude the occurrence of problems analogous to those that occurred in the airline and other related industries.

There is much work to be done by NASA and its contractors. Some facilities already exist which can be used to pursue this endeavor. Funding is necessary for refurbishment and modification of these facilities as well as for the creation of new simulators with increased capabilities and applications. To accomplish the goals of acquiring a better understanding of the manual control aspects of orbital flight, NASA should be prepared to participate actively and to operate in a leadership role.

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MANUAL CONTROL ASPECTS OF ORBITAL FLIGHT

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Studies of spacecraft rendezvous and docking operations began in the Gemini program in preparation for the two dockings required to send a crew to the moon and return them safely to Earth. However, the goal of getting to the moon before the end of the decade was of greater concern than mission optimization so little or no time or money was expended in researching human factors implications of operational aspects such as braking gates or control modes. Also, with sixteen operational dockings over a six year period (12 Apollo, 3 Skylab, 1 ASTP) in the United States space program, economies of scale were not yet available to justify extensive research into decreasing the time or fuel necessary for a successful docking. By analogy, the Wright brothers did not "waste" time developing glide slopes or rules of thumb to follow; they just wanted to get off the ground. With an operational space station era approaching in which orbital maneuvering vehicle (OMV), orbital transfer vehicle (OTV), shuttle orbiter, and other traffic will play a major role, a concerted research effort now could help avoid many potential problems later in addition to increasing safety, fuel economy, and productivity. A knowledge of manual control capabilities associated with piloted spaceflight could help save a life if the operational flight envelope can be safely enlarged to include faster dockings than currently envisioned, for example. Current and future research is designed to acquire the appropriate information.

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ORBITAL MANEUVERING VEHICLE REMOTE PILOTING OPERATIONS

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ABSTRACT

The subject of this paper is the remote piloting of spacecraft. The Orbital Maneuvering Vehicle (OMV) is used as a case in point. Some challenges to remotely piloted operations are listed. Approaches to solving operational problems are discussed for the two major participants in the loop tasks involved. These tasks are the remotely piloted docking task, and the task of ensuring that the rendezvous is successfully completed. Resulting changes to the OMV system are outlined. The outcome of these changes and the approaches taken in the OMV program are presented. Comparisons are drawn between philosophies and techniques used for STS rendezvous and proximity operations, and those currently envisioned for OMV. Finally, a few "lessons learned" are summarized.

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RESULTS FROM TELEOPERATED FREE-FLYING SPACECRAFT SIMULATIONS IN THE MARTIN MARIETTA SPACE OPERATIONS SIMULATOR LAB

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To augment the capabilities of the space transportation system, NASA has funded studies and development programs aimed at developing reusable, remotely piloted spacecraft and satellite servicing systems capable of delivering, retrieving, and servicing payloads at altitudes and inclinations beyond the reach of the present Shuttle Orbiters. Since the mid 1970's researchers at the Martin Marietta Astronautics Group Space Operations Simulation (SOS) Laboratory have been engaged in investigations of remotely piloted and supervised autonomous spacecraft operations. These investigations have been based on high fidelity, real-time simulations and have covered a wide range of human factors issues related to controllability. Among these are (1) mission conditions including thruster plume impingements and signal time delays; (2) vehicle performance variables including control authority, control harmony, minimum impulse, and cross coupling of accelerations; (3) maneuvering task requirements such as target distance and dynamics; (4) control parameters including various control modes and rate/displacement deadbands; and (5) display parameters involving camera placement and function, visual aids, and presentation of operational feedback from the spacecraft. This presentation will include a brief description of the capabilities of the SOS Lab to simulate real-time free-flyer operations using live video, advanced technology ground and on-orbit workstations, and sophisticated computer models of on-orbit spacecraft behavior. It will then provide sample results from human factors studies in the five categories cited above. Reprints of key papers written by lab personnel will also be available.

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A MANNED MANEUVERING UNIT PROXIMITY OPERATIONS PLANNING AND FLIGHT GUIDANCE DISPLAY AND CONTROL SYSTEM

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This task concerns the design, development, testing, and evaluation of a new proximity operations planning and flight guidance display and control system for manned space operations. A forecast, derivative Manned Maneuvering Unit (MMU) has been identified as a candidate for the application of a color, highway-in-the-sky display format for the presentation of flight guidance information.

A Silicon Graphics 4D/20-based simulation is being developed to design and test display formats and operations concepts. The simulation includes real-time color graphics generation to provide realistic, dynamic flight guidance displays; real-time graphics generation of spacecraft trajectories; MMU flight dynamics and control characteristics; control algorithms for rotational and translational hand controllers; orbital mechanics effects for rendezvous and chase spacecraft; inclusion of appropriate navigation aids; and measurement of subject performance.

The flight planning system under development provides for selection of appropriate operational modes, including minimum cost, optimum cost, minimum time, and specified ETA; automatic calculation of rendezvous trajectories, en route times, and fuel requirements; and provisions for manual override. Man/machine function allocations in planning and en route flight segments are being evaluated.

Planning and en route data are presented on one screen composed of two windows: (1) a map display presenting a view perpendicular to the orbital plane, depicting flight planning trajectory and time data attitude display presenting attitude and course data for use en route and (2) an attitude display presenting local vertical-local horizontal attitude data superimposed on a highway-in-the-sky or flight channel representation of the flight planned course. Both display formats are presented while the MMU is en route. In addition to these display formats, several original display elements are being developed, including a three-degree-of-freedom flight director for attitude commanding, a different flight director for translation commands, and a pictorial representation of velocity deviations.

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INTERACTIVE ORBITAL PROXIMITY OPERATIONS PLANNING SYSTEM

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An interactive graphical planning system will be presented for on-site planning of proximity operations in the congested multispacecraft environment about the space station. The system shows the astronaut a bird's-eye perspective of the space station, the orbital plane, and the co-orbiting spacecraft. The system operates in two operational modes: a viewpoint mode, in which the astronaut is able to move the viewpoint around in the orbital plane to range in on areas of interest; and a trajectory design mode, in which the trajectory is planned. Trajectory design involves the composition of a set of waypoints which will result in a fuel-optimal trajectory which satisfies all operational constraints, such as departure and arrival constraints, plume impingement constraints, and structural constraints. The main purpose of the system is to present the trajectory and the constraints in an easily interpretable graphical format. Through a graphical interactive process, the trajectory waypoints are edited until all operational constraints are satisfied. A series of experiments was conducted to evaluate the system. Eight airline pilots with no prior background in orbital mechanics participated in the experiments. Subject training included a stand-alone training session of about 6 hours duration, in which the subjects became familiar with orbital mechanics concepts and performed a series of exercises to familiarize themselves with the control and display features of the system. They then carried out a series of production runs in which 90 different trajectory design situations were randomly addressed. The purpose of these experiments was to investigate how the planning time, planning efforts, and fuel expenditure were affected by the planning difficulty. Some results of these experiments are presented.

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SIMULATED ANNEALING IN ORBITAL FLIGHT PLANNING

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Simulated annealing is used to solve a minimum fuel trajectory problem in the space station environment. The environment is unique because the space station will define the first true multivehicle environment in space. The optimization yields surfaces which are potentially complex, with multiple local minima. Because of the likelihood of these local minima, descent techniques are unable to offer robust solutions. Other deterministic optimization techniques were explored without success. The simulated annealing optimization is capable of identifying a minimum-fuel, two-burn trajectory subject to four constraints. Furthermore, the computational efforts involved in the optimization are such that missions could be planned on board the space station. Potential applications could include the on-site planning of rendezvous with a target craft or the emergency rescue of an astronaut. Future research will include multiwaypoint maneuvers, using a knowledge base to guide the optimization.

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16. Abstract

This publication provides a brief description of several laboratories' current research in the general area of manual control of orbital flight. This research began in the 1960's in preparation for the Gemini and Apollo programs, but documentation for any work performed over the last twenty years is virtually nonexistent. With an operational-space-station era (and its accompanying increased traffic levels) approaching, now is an opportune time to investigate issues such as docking and rendezvous profiles and course-planning aids. The tremendous increase in the capabilities of computers and computer graphics has made extensive study possible and economical. It is time to study these areas, from a human factors and manual control perspective, in order to preclude the occurrence of problems analogous to those that occurred in the airline and other related industries.

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